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General Aviation Aircraft Meeting and Exposition
Wichita, Kansas
April 16-19, 1985

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ADVANCED SYSTEMS FOR THE GULFSTREAM IV

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ABSTRACT

The high performance Gulfstream IV corporate jet aircraft features several advanced systems. These include solid state electric power generation, digital electronics in conjunction with an integrated avionics system and electronic control of subsystems. The development and design of the various advanced subsystems into an efficient, integrated aircraft plan is a challenge to the engineers. The Gulfstream IV incorporates state-of-the-art systems with proven technology gained from private and government research. Some concepts are a first for use on commercial aircraft. The unique system requirements for the Gulfstream IV lay in a grey area between that normally used on general aviation aircraft and large commercial airliners. Operators demand performance that many times exceed the standard for both of these categories.

THE GULFSTREAM IV (GIV) AIRPLANE is a long range, high performance jet, manufactured by Gulfstream Aerospace Corporation. The airplane is considered to be the top-of-the-line model for corporate operators as well as many government agencies. Two aft mounted Rolls-Royce Tay engines rated at 12,450 pounds thrust (SL) each provide excellent performance at both low and high altitudes at maximum gross weight. The medium bypass ratio (3.0) engines provide excellent efficiency along with meeting all current and proposed noise regulations.

The airplane is large in comparison to general aviation aircraft with a gross weight of 70,200 pounds and a wing area of 958 square feet. Certification is for 19 passengers plus crew and can fly eight passengers and baggage with three crew members 4300 nautical miles NBAA IFR at .8M. Cruise altitudes will be at 45,000 feet and higher. An on-board auxiliary power unit (APU) makes the aircraft self-supporting at remote airfields.

Gulfstream history started back in the 1950's with the twin turbo prop Gulfstream I. One hundred, ninety-five are flying in service today. Over two hundred, fifty twin turbojet Gulfstream II's were manufactured in the late 1960's and 1970's. The twin turbojet Gulfstream III is currently in production with more than one hundred and fifty airplanes delivered to worldwide customers, including private industry and government agencies. The Gulfstream II and III aircraft routinely makes intercontinental flights. In 1984, a Gulfstream III completed record making flights around the earth east to west and pole to pole.

This discussion presents some of the highlights of the advanced systems on the Gulfstream IV. A comprehensive review of all Gulfstream IV systems is not attempted, nor is a complete system description presented.

ADVANCED COCKPIT DISPLAY

The Gulfstream IV cockpit display system is the most dramatic advance, featuring six identical color 8 x 8 inch cathode ray tubes (CRT) or display units (DU) as shown in Figure 1. Two DU's for each pilot consists of a primary flight display (PFD) and a navigation (NAV) display. The two center DU's display engine instruments, crew alerts/messages and subsystem status. The PFD provides the basic "T" parameters of attitude, heading, airspeed, altitude and vertical speed. Pilot cues for airspeed, course and navigation mode are presented. The NAV display provides various navigation formats including VOR, ADF, FMS, ILS and MLS. Weather radar displays are also on the NAV unit.

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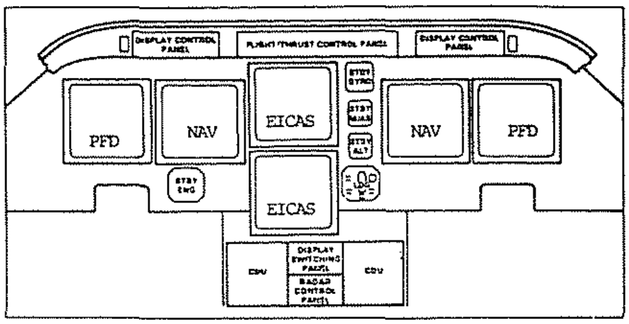

FIGURE 1 - COCKPIT DISPLAY

The crew can control the display formats to show more or less information as required. The formats vary with flight condition to reduce clutter and provide extremely effective integrated display presentations. For example, the crew can request display of all airports within the displayed range from the aircrafts present position at any given time. Aircraft route, vertical profile and approach path can be displayed in various formats.

The color CRT's provide a very flexible tool for the human factors engineer in the development of formats displayed. For example, the engine instrument parameters change color when limits are exceeded. Compacted formats are presented in the event of a tube failure. As discussed in several reports, this flexibility must be carefully controlled and evaluated to prevent overwhelming the pilot with information and to ensure proper interpretation of the display in a timely manner.

INTEGRATED AVIONICS

The Gulfstream IV utilizes digital avionics design concepts. ARINC 429 and Aircraft Standard Communications Bus (ASCB) are digital busses used to communicate between the various equipment. The digital data bus features include fail operational mode and high speed, bi-directional transmissions, and reduce the amount of wiring required.

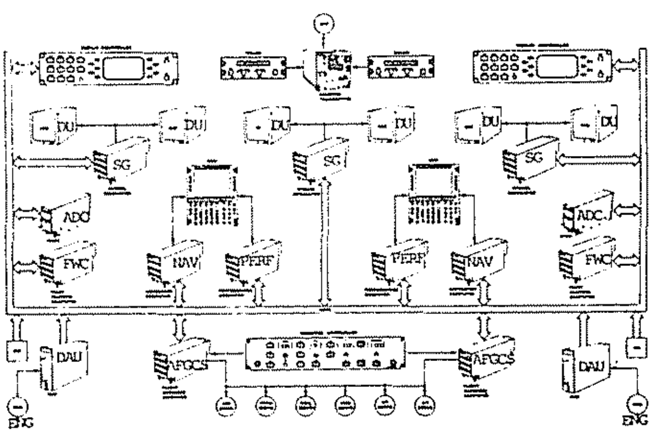

FIGURE 2 - INTEGRATED AVIONICS SYSTEM

FLIGHT MANAGEMENT SYSTEM

The Flight Management System (FMS) is designed as a federated system, where independent components performs system functions. Each FMS includes a control display unit (CDU), a navigation computer and a performance computer. FMS features include a large world wide data base, large flight plan storage, pilot defined waypoints, integrated lateral navigation (LNAV) and vertical navigation (VNAV), auto cross-load, flight planning (fuel, time, altitude), engine power settings, takeoff calculations, climb/cruise/descent speeds, step-climb points, landing calculations, go-around calculations and engine out parameters.

The CDU is the primary means for pilot input into the system. It contains a full alpha-numeric keyboard and color CRT display for inputs and outputs from the navigation and performance computers.

The navigation computer provides lateral and vertical guidance. The data base storage consists of waypoints, nav aids, routes, airports, and other navigation data for easy access by the crew. The data base is updated monthly. Communications with onboard navigation sensors develop an airplane FMS position based on a blend or mix of the sensors for a precise position fix. Navigation management allows a route definition from airplane present position to any point in the world. Functions of this computer also include automatic radio tuning, map displays and automatic holding patterns.

The performance computer determines optimum airspeed/engine setting for particular flight conditions and airplane configuration (gross weight and C.G.). This includes the takeoff roll, climb, cruise, descent and landing. It also functions as an auto throttle computer to directly control throttles to optimize thrust management. An advisory or full active mode can be selected. Capabilities of the FMS include airplane takeoff acceleration advisories and contaminated runway takeoff performance data amoung others.

FLIGHT GUIDANCE SYSTEM

The dual Automatic Flight Guidance Control System (AFGCS) features fail-operational modes and Category III autoland capabilities. Each AFGCS includes a flight guidance computer, flight guidance control panel and dual servo's for aileron, elevator, elevator trim and rudder control. Functions include two-axis flight director, pitch and roll autopilot, yaw damper control and mach trim compensator. Three-axis accelerometer data from the lasor inertial reference units is used extensively for flight guidance accuracy. Flight path limits are programmed to hold desired maneuvers without exceeding comfortable forces and roll rate. The fail-operational concept operates with one computer active and one hot standby doing all the same processing as the active unit. If

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the active computer fails, the standby computer automatically takes control without disconnecting the autopilot. Each AFGCS computer is designed fail-passive through the use of dual microprocessors and redundant data paths to each processor. Monitoring techniques protect against safety critical failures, resulting from either a hardware failure or a latent software error. Multiple sensor inputs are continuously monitored for differences and invalid data.

DISPLAY SYSTEM

The display system consists of the six 8 x 8 inch color CRT units and three symbol generators. Each of the identical symbol generators can drive four CRT units. In normal operation, each symbol generator operates two CRT units. The symbol generators receive information via the ASCB data bus from the flight management system, flight guidance system, engine instrument and crew alerting system, and aircraft sensors.

ENGINE INSTRUMENT AND CREW ALERTING SYSTEM

The engine instrument and crew alerting system (EICAS) provides engine information and aircraft systems status to the display system for presentation on the two center CRT units. The EICAS consists of two fault warning computers (FWC) and two data acquisition units (DAU). These computers interface with the engine and aircraft system sensors via analog, discrete and ARINC 429 data bus communication lines. The computers also record engine and aircraft data for trend monitoring. This information goes into a nonvolatile memory which can be extracted periodically and analyzed.

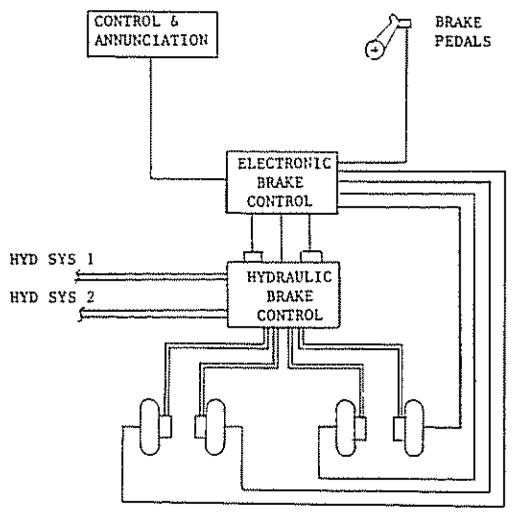

FIGURE 3 - BRAKE SYSTEM

BRAKE-BY-WIRE SYSTEM

Control of the hydraulic brakes is accomplished by a redundant digital electronic system. Brake pedal transducers provide input to the electronic brake control unit. The brake control unit operates the hydraulic brakes with or without anti-skid as selected by the crew. For anti-skid operation wheel speed is sent to the brake control unit from individual wheel transducers. Benefits obtained from this system include extensive function monitor and built-in-test (BITE), exceptional runway performance with smooth braking characteristics and reduction in system weight.

CARBON BRAKES

Carbon brakes were introduced on the Gulfstream III and will be used on the Gulfstream IV. The carbon disk brakes replaced the steel brakes at a weight savings of over ninety pounds. The maximum energy is 19.5 million foot-pounds per brake. The performance of the carbon brakes in service has been very good with no major problems encountered. Improvements were made on the steel clips attached to the rotating carbon disks to eliminate clip breakage. Some uneven braking was encountered at low taxi speeds and was corrected by modifying the brake hydraulic system to provide a faster response in brake pressure applied and feedback feel at the pilots brake pedals.

STEER-BY-WIRE SYSTEM

Control of the hydraulic nose wheel steering unit is accomplished by a fail passive electronic system. Pilot input to the electronic control unit is via the handwheel and/or rudder pedals. The electronic control unit output regulates the hydraulic flow and pressure to the steering unit according to the steering rate input by the pilot and the transducer feedback signal. A weight-on-wheels signal prevents steering unit commands while airborne and provides a ramped input if a steering command exists on nose wheel touchdown. Critical functions within the system are monitored and a failure will disable the control.

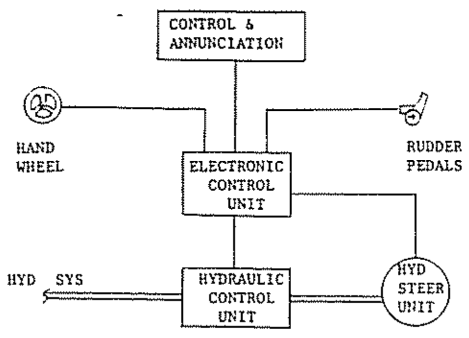

FIGURE 4 - STEERING SYSTEM

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ELECTRIC POWER GENERATION

A variable-speed-constant-frequency (VSCF) electric power system was certified on the Gulfstream III and will be utilized on the Gulfstream IV. The VSCF system replaced the heavy, inefficient transformer-rectifiers, inverters and DC generators. The VSCF is a solid state system with the only moving parts being the AC generators and cooling fans. This is the first commercial aircraft application of a VSCF system. Versions of VSCF systems have been used in military applications.

The electric power is a dual channel system with either channel capable of supplying power for the entire airplane. The automatic control and monitoring features provided reduce pilot workload considerably. This includes the proper bus to available power source selection from ground power, APU, to the main engine generators. In the event of any in-flight malfunctions, the controls will automatically connect the proper available power sources to the bus distribution system.

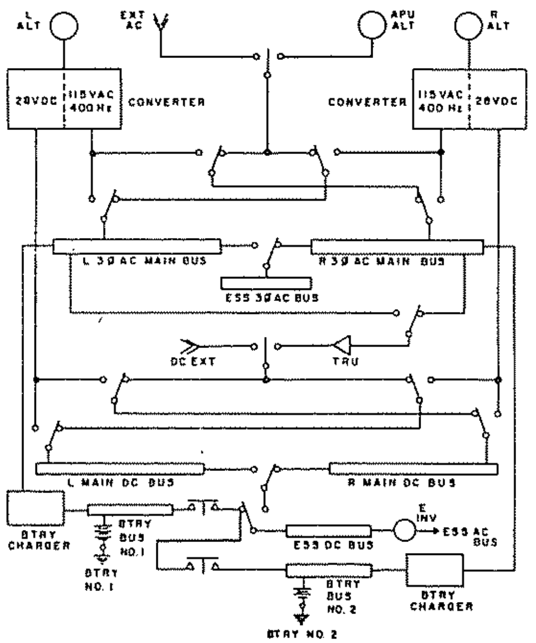

FIGURE 5 - ELECTRIC POWER SYSTEM

The electronic converter is the heart of the system. Utilizing high-speed, high-power transistor circuits, the converter takes variable frequency output provided by the conventional AC generators, rectifies it, converts it into square wave outputs, then sums up these outputs into a transformer to produce a high quality, closely regulated source of electric power. Each of the converters can provide 23 kVA 400 hertz 115 volt AC power and 250 amperes 28 volt DC power. The converters normally operate at less than 50 percent power. Additional backup power is available from a flight rated APU driven AC generator, a hydraulic driven motor-generator and two nickel-cadmium batteries.

The efficient (85 percent overall) VCSF system eliminated losses (approximately 6kVA) on the previous system of producing 400 hertz AC power through conventional transformer-rectifiers and converters.

The VSCF system is operating on over fifty aircraft in service at the present time. The Gulfstream III that made the around the world trips had this system. The power generation by the VSCF concept has been proven by testing and the performance on aircraft in service. A complex system of this magnitude had several problems develop during the initial introduction phase. These were associated with the control and protective functions which are quite complex due to the automated features incorporated. These interacting circuits proved to be susceptible to EMI noise and timing problems. Eliminating the noise problems in the control circuits was a matter of identifying the source by tests and eliminating or providing protection from it. Slight changes in the control circuit timing was made after testing identified the problem. Some of these problems only occurred at a particular temperature or power setting. Very tight manufacturing control of the integrated circuits was required to prevent any damage to components and printed circuit boards during production and testing.

SUMMARY

The advanced technology built into the Gulfstream IV provides excellent performance with efficiency. The flexibility provided to the operator allows completion of the mission whether short range or long range to any point on the earth. The aircraft is self-sufficient with the on-board systems which can meet the demands of various missions. Completion of these missions is ensured by the system capabilities provided. Missions can be completed at the most efficient cost, least time or combinations thereof and can be automated from the takeoff roll through climb, cruise, descent and landing in almost any weather conditions. The tools to provide the data for these decisions are built into the aircraft systems and provide accurate predictions of time, distance, altitude, speed, and position.

BIBLIOGRAPHY

Sperry Avionics for the Gulfstream IV - Sperry Avionics Division, 1984

Variable Speed Constant Frequency for the Gulfstream III - Bendix Electric Power Division, 1981

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